13.—Rainfall and Soil Control of Tree Species Distribution around Narrogin, Western Australia

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Manuscript received—21st April, 1960

In an area around Narrogin, Western Australia, soils relate to erosional and depositional surfaces, and to rainfall. Tree species incidence also relates to the surfaces and to rainfall. Relationships between surfaces, soils, tree incidence and rainfall are presented. Evidence is also produced for species migrations and this is discussed in terms of the climatic and geomorphic history of the area.

Introduction

This report is of an autecological study of the relationships of twelve tree species to the rainfalls and soils in an area of transition in Western Australia, and concerns the extent to which these environmental factors and their histories control the tree distributions. The area of study (Figs. 1 and 2) surrounds the township of Narrogin (lat. 32° 56′ S. long. 117° 11′ E.). It constitutes a rectangular strip of about 700 square miles between Cuballing in the north and Highbury in the south, from Williams in the west to Toolibin in the east, and is extensively cleared for agricultural purposes.

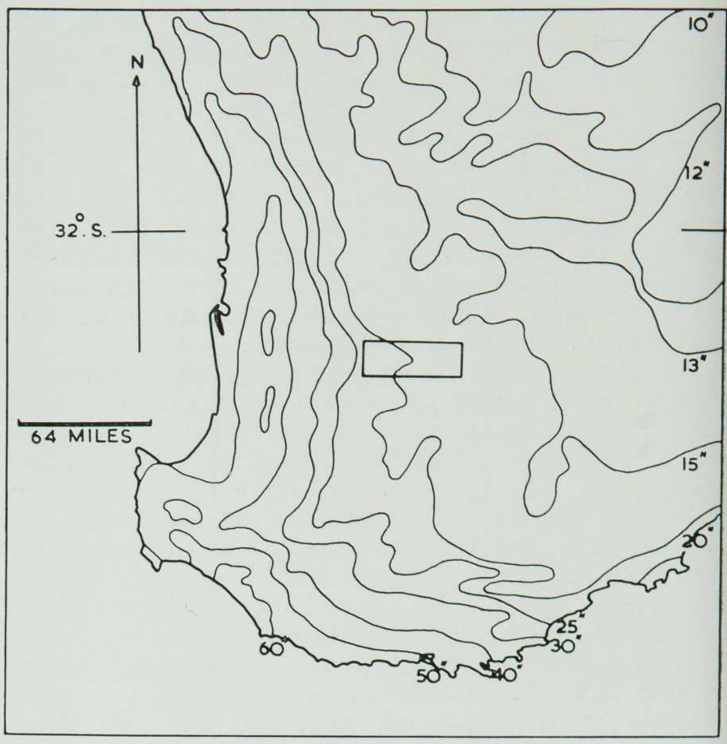

Fig. 1.—Locality plan and rainfall distribution.

The Environment

Climate

The area occurs in a climatic zone of winter rainfall and summer drought (Gentilli 1956), and the rainfall distribution in the area is illustrated in Fig. 1. The annual precipitation decreases on a fairly even gradient from 25″ of annual rainfall west of Williams to 15″ per annum in the east of the area.

Geology

The parent rocks in the area are the Precambrian granites and gneisses of the West Australian Shield, with occasional basic intrusions (Wilson 1958).

Geomorphology and Soils

The relief and drainage in the area are shown diagrammatically in Fig. 2, which shows both drainage west to the sea, and east to the salt lake systems, hence the area includes elements of Jutson's Swanland and Salinaland physiographic divisions (Jutson 1955). According to Jutson, the lateritic peneplain or "old plateau" of Western Australia occurs in the former division as the Darling Plateau, and in the latter division as relicts, particularly in the form of mesas and buttes. Normal erosion in the stream-bearing Swanland division is not sufficiently advanced to obscure the old plateau, but Salinaland exhibits a new plateau of arid erosion, and the boundary between the two divisions is the line separating rivers of the coast from interior drainage.

In the study area, drainage west occurs in relatively sharp valleys, while that to the east occurs in broad flat-bottomed ones, constituting western extensions of Jutson's "new plateau" of arid erosion. In the study area, the old plateau is largely destroyed, and is preserved only as residuals on the divides. At York, Mulcahy (1959) studied the soils of the old plateau, and the erosional and depositional surfaces resulting from its breakdown, and showed that the distribution of these surfaces determines the distribution of soils. A similar series of erosional and depositional surfaces occur in the study area, and although some have no described equivalents near York, most are the equivalents of surfaces described by Mulcahy.

The distribution of the surfaces themselves is controlled by the geomorphic history of the area, and the older surfaces are distinctly relicts left after the destruction of a great deal of their previous extensions. These latter have the bulk of their present distributions west of the study area. The oldest surface in the study area (Quailing erosional) is laterite, of Jutson's lateritic peneplain or "old plateau," but lateritic

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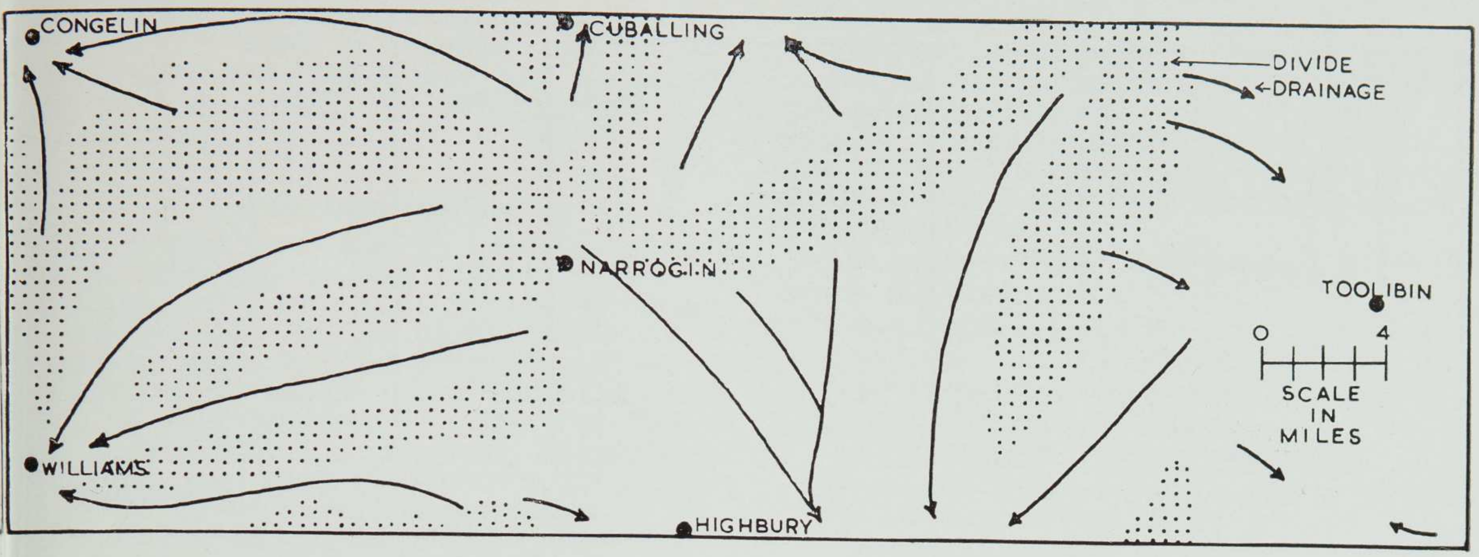

Fig. 2.—Relief and drainage.

profiles are not confined to the much modified old plateau preserved on the divides. They are found also as residual spurs and terraces on valley sides and floors respectively, representing an early phase of erosion cutting into the old plateau. Subsequent erosions and depositions have given rise to younger surfaces which carry soils developed on the truncated older lateritic surfaces, or, where more deeply cut, soils developed on exposed fresh rock.

This situation contrasts markedly with that pertaining in the high rainfall zone of the Darling Range, to the west of the study area. That area, although much dissected, carries laterite detrital material on valley sides and floors and this is often recemented such that nearly all soils are laterites. Thus laterites in the study area can be regarded as outliers.

In the east of the study area some of the younger laterites of valley sides were found to be calcareous. Considering the origin of laterite (Prescott and Pendleton 1952), this lime must be *secondary*, i.e. brought in by wind or ground water. Laterite development followed by the occurrence of secondary lime clearly indicates formation in a wet climate, followed by relatively arid conditions.

In the study area, there is a close correlation between the surfaces and their associated soil types, and surfaces encountered in the area are listed below, against their topographical position and soil characteristics.

(1) *Surfaces located on divides.*

Quailing erosional.—Massive residual laterite or heavy ironstone gravel.

Quailing depositional.—Deep yellow sands. Deposit derived from laterite.

Degraded Quailing erosional.—Laterite residuals reduced to a thin veneer of ironstone gravel over pale reddish clays resembling those of the Balkuling surface (q.v.).

Kauring.—Grey sand over massive ironstone.

Monkopen.—Deep grey sand in depressions.

Granite outcrop and associated sandy deposits.—Shallow skeletal soils and associated deep sandy and gritty soils.

(2) *Surfaces located on valley slopes and interfluves.*

Belmunging.—Spurs and ridges carrying ironstone gravelly soils extending from the divides down towards the drainage lines. May be calcareous in the east of the area.

Breakaway face.—Pediments below the breakaways, carrying pale reddish and greyish clayey soils, often with a thin scree of ironstone gravel. May be calcareous in the east of the area.

Malebelling erosional.—Brownish gritty sands over yellow and red mottled weathered rocks.

Malebelling depositional.—Brown or greyish-brown gritty sands, often with a prominent bleached A_2 horizon over variously mottled weathered rock.

York.—Brown loams and loamy sands over reddish-brown clays. Close to drainage lines.

(3) *Surfaces located on valley floors.*

Avon.—Brown or grey clay at the surface.

Mortlock.—Lateritic valley terrace.

Truncated Mortlock.—Grey sands over domed clay. Often calcareous in deep sub-soil.

Sandy alluvium.—Brown sand over yellow clay. Not calcareous.

Flood plain sands.—Sandy deposits of braided stream pattern associated with the lake system in the eastern part of the area.

Baandee.—Resemble deposits at Baandee (Bettenay, priv. comm.). Fine textured calcareous aeolian deposits associated with lakes in the south-eastern part of the area.

(4) *Fresh complex.*

The situation pertaining in principal water-courses.

The outstanding edaphic discontinuity in the area occurs at the 20″ annual rainfall isohyet, which marks the region of transition between external and internal drainage. Avon, Truncated Mortlock, Sandy Alluvium and Baandee surfaces of arid erosion occur in valley floors to the east of that isohyet only, together with all calcareous soils, and thus the 20″ annual rainfall isohyet marks a pedocal-pedalfer boundary in the area. Calcareous soils occur to the

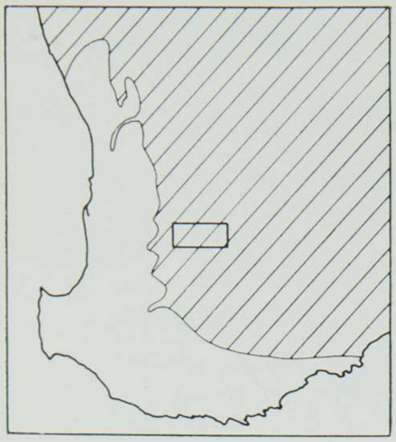

Fig. 3.—*A. acuminata*

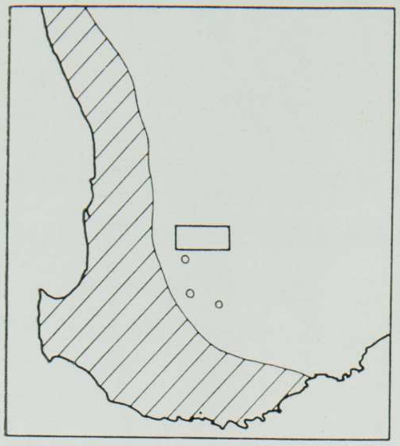

Fig. 4.—*B. grandis*

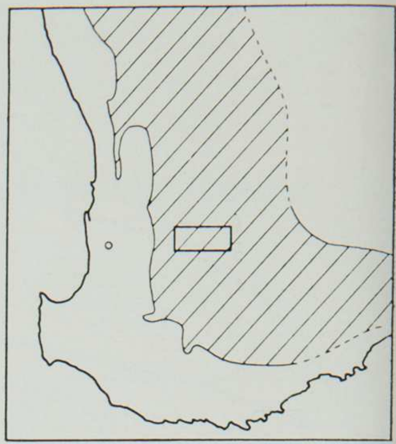

Fig 5.—*C. huegeliana*

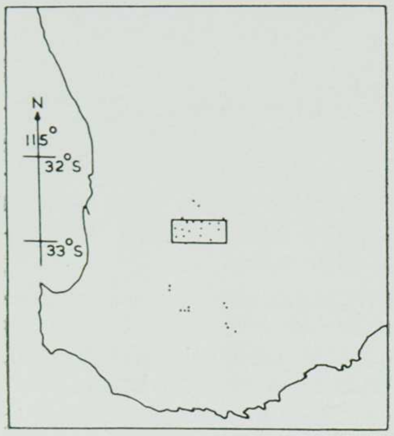

Fig. 6.—*E. astringens*

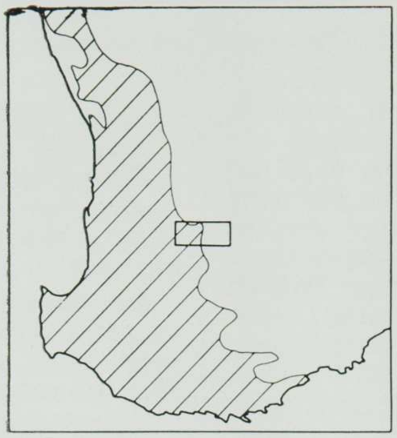

Fig. 7.—*E. calophylla*

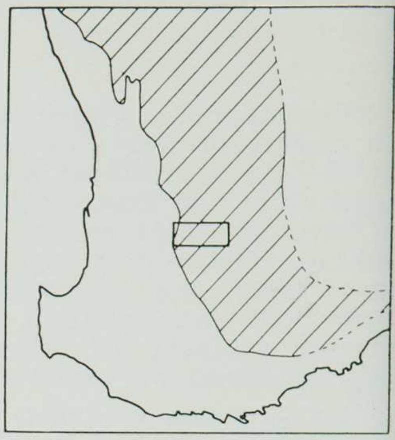

Fig. 8.—*E. loxophleba*

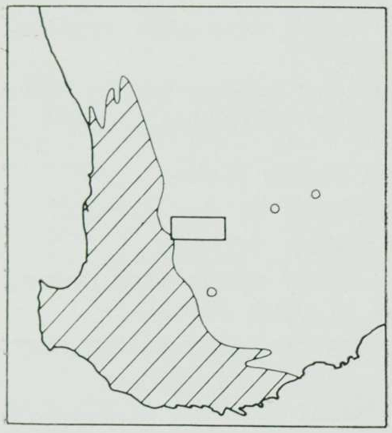

Fig. 9.—*E. marginata*

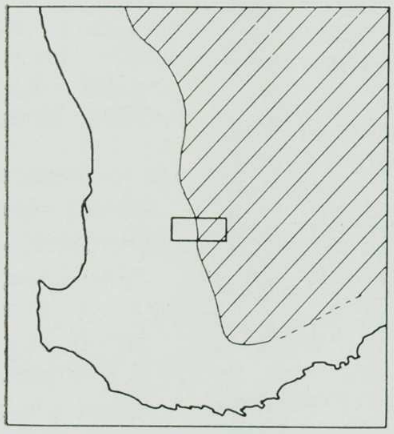

Fig. 10.—*E. longicornis*

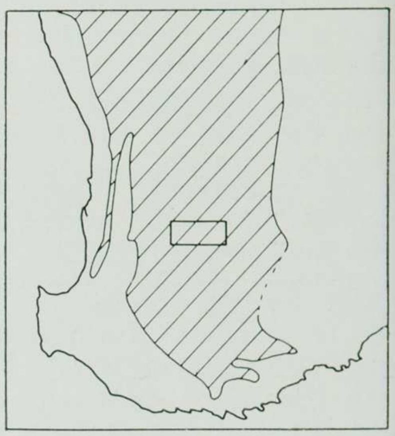

Fig. 11.—*E. redunca* var. *elata*

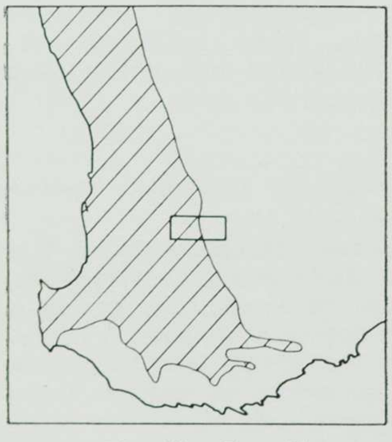

Fig. 12.—*E. rudis*

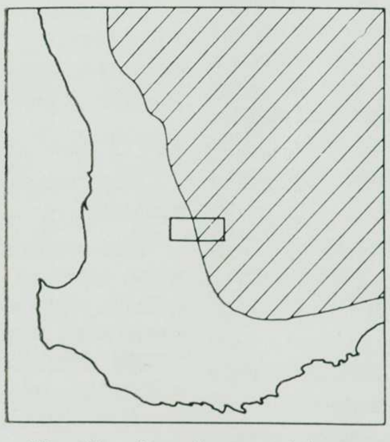

Fig 13.—*E. salmonophloea*

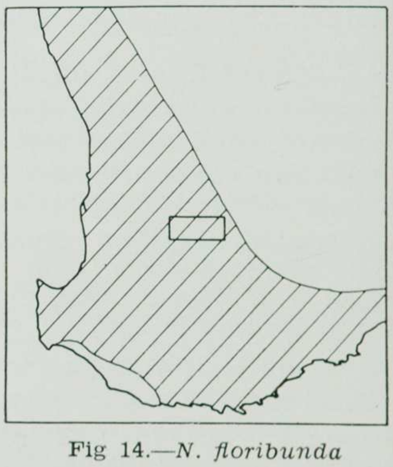

Fig 14.—*N. floribunda*

Figs. 3-14.—Known distributions of the twelve tree species in south-western Australia (from unpublished data of Churchill and Storr).

east only, and occur even on some relict lateritic surfaces. Soils on western surfaces are characteristically without lime, and a relationship between rainfall and soil distributions is thus apparent.

Tree Distributions

The twelve tree species *Acacia acuminata* Benth., *Banksia grandis* Willd., *Casuarina huegeliana* Miq., *Eucalyptus astringens* Maiden, *E. calophylla* R. Br., *E. loxophleba* Benth., *E. marginata* Sm., *E. longicornis* F. v. M., *E. redunca* Schau. variety *elata* Benth., *E. rudis* Endl., *E. salmonophloea* F. v. M. and *Nuytsia floribunda* (Labill.) R. Br. were considered in this study, and their total known distributions in south-western Australia are shown in Figs. 3-14. Precise data of this kind are not available from published sources, and Figs. 3-14 have been drawn from unpublished surveys by D. M. Churchill* and G. M. Storr†.

Drastic changes in the distribution of tree species have occurred since the study area was cleared. Clearing commenced about one hundred years ago, and the arable land is now almost entirely cleared. Original distributions are now represented in skeletal patterns only, on fencelines and roadsides, in uncleared patches of arable and non-arable land, and in reserves. Clearing has resulted in rapid soil salinity changes (Teakle 1938) and current expansion of agriculture is resulting in the destruction of even relict distributions. *Santalum spicatum* (R. Br.) D.C. has been completely removed from the area by commercial cutters. By the use of a grid square-tree incidence system of plotting, the virgin distributional patterns of the 12 species were reconstructed,

Traverses were made throughout the area to view within two miles of any point, and the tree species incidence was recorded at intervals not exceeding one mile, on these traverses. Species-locality records from traverse data were plotted on maps of the area scaled at 4 miles to the inch and gridded in 2-mile squares, and grid squares were rated as positive if species-locality records occurred within them. Continuity of adjoining positive grid squares was taken as continuity of distribution, and two kinds of geographic distributions were recognised.

(1) *Continuous distributions.* Certain distributions exhibited continuity over an area exceeding 350 square miles and typically extending continuously across the boundary of the study area, with relatively high densities throughout grid squares. These distributions were termed *continuous.*

(2) *Disjunct distributions.* The remaining distributions exhibited continuity over an area not exceeding 30 square miles, and typically over a much smaller area, with relatively low densities, typically of single stands and often of only three or four trees. These distributions were termed *disjunct.*

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Distributions of the twelve species in the area are presented individually in Figs. 15-26, where *continuous* distributions are plotted with closed circles representing the centres of positive grid squares. *Disjunct* distributions are located by open circles. The twelve species may be grouped on the similarities of their geographic distributions in the area:

(1) Species with continuous distribution across the area:

- (a) *Acacia acuminata.*
- (b) *Casuarina huegeliana.*
- (c) *Eucalyptus astringens.*
- (d) *Eucalyptus loxophleba.*
- (e) *Eucalyptus redunca* var. *elata.*

(2) Species with continuous distribution *west* of the 20″ annual rainfall isohyet only:

- (a) *Eucalyptus calophylla.*
- (b) *Eucalyptus rudis.*

(3) Species with continous distribution *east* of the 20″ annual rainfall isohyet only:

- (a) *Eucalyptus longicornis.*
- (b) *Eucalyptus salmonophloea.*

(4) Species with disjunct distribution:

- (a) *Banksia grandis.*
- (b) *Eucalyptus calophylla.*
- (c) *Eucalyptus marginata.*
- (d) *Nuytsia floribunda.*

Comparisons with Figs. 3-14 places Figs. 15-26 in perspective. The study area lies in a zone of distribution margins and contains the eastern extension of some species of western distribution (*E. calophylla, E. rudis*) and western extensions of some eastern distributions (*E. longicornis* and *E. salmonophloea*). It brackets the distribution of *E. astringens* and falls within the distribution of *A. acuminata, C. huegeliana, E. loxophleba* and *E. redunca* var. *elata.* It also contains disjunct distributions, and these are *all* of species now distributed *west* of the study area.

Tree Distributions in Relation to Rainfalls and Soils

In south-western Australia there is no marked relief or climatic range, and it is recognized that plant distributions generally are controlled primarily by rainfall and soils (Gardner 1942). The total distributions of the 12 species (Figs. 3-14) illustrate this on comparison with the rainfall map (Fig. 1). Seven of the study species exhibit distributional margins in the study area. *E. calophylla, E. longicornis, E. rudis and E. salmonophloea* exhibit a fairly mutual boundary of distribution at the 20″ annual rainfall isohyet and the related pedocal-pedalfer boundary. Disjunct distributions are all atypical of the rainfall relationships of their species in that they occur in *lower* rainfall areas. Thus the typical lower-rainfall limit for *E. calophylla* is 20 ″ (Fig. 7), and the disjunct *E. calophylla* distribution at Toolibin occurs in a 15″ rainfall. Similarly the disjunct distributions of *B. grandis, E. marginata* and *N. floribunda* occur in rainfalls below the typical lower limit for the species. However, all disjunct distributions east of the 20″ isohyet are associated with the high ground-water effect (Mulcahy 1959).

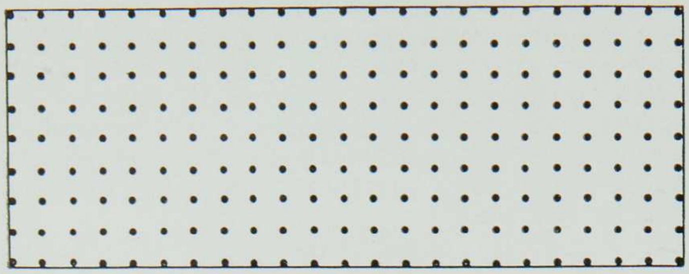

Fig. 15.—*A. acuminata*

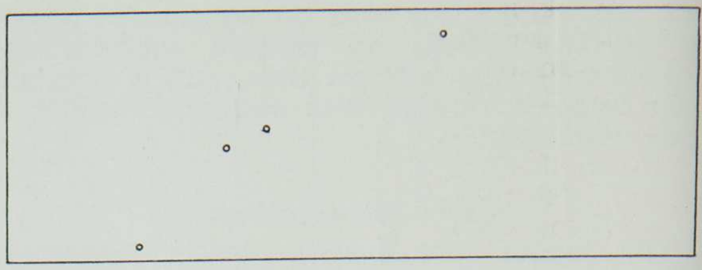

Fig. 16.—*B. grandis*

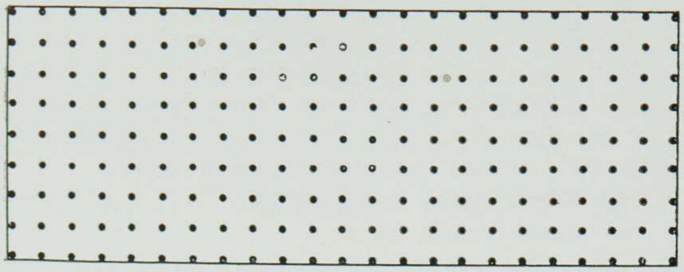

Fig. 17.—*C. huegeliana*

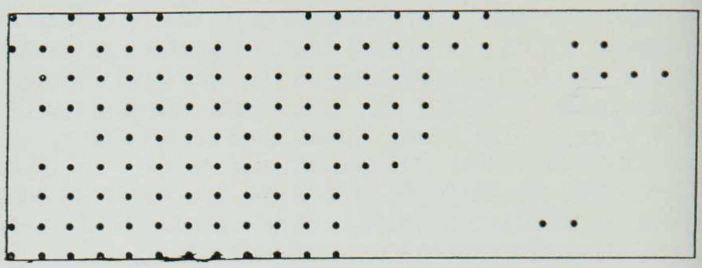

Fig. 18.—*E. astringens*

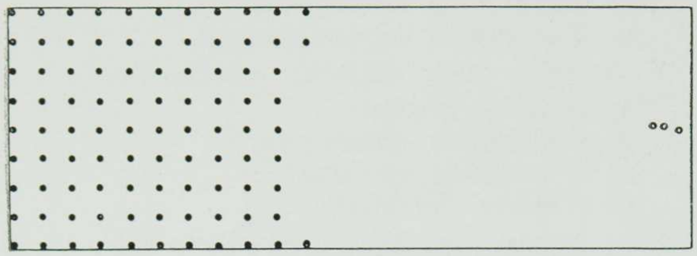

Fig. 19.—*E. calophylla*

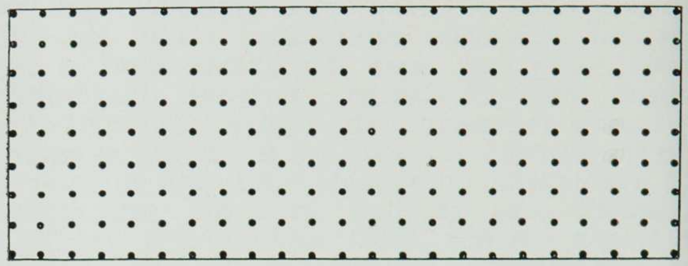

Fig. 20.—*E. loxophleba*

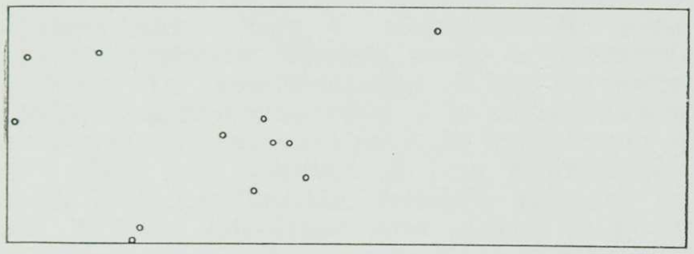

Fig. 21.—*E. marginata*

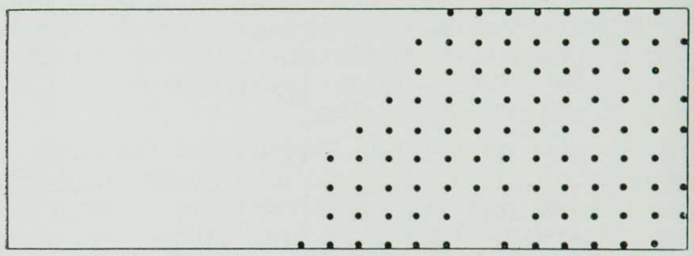

Fig. 22.—*E. longicornis*

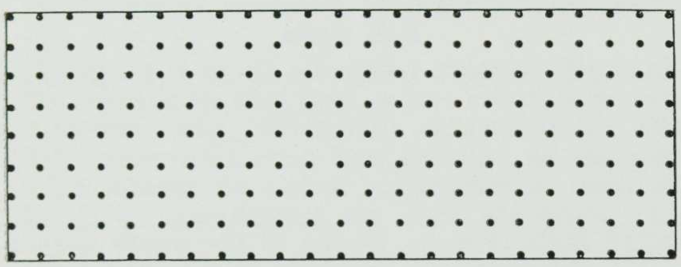

Fig. 23.—*E. redunca* var. *elata*

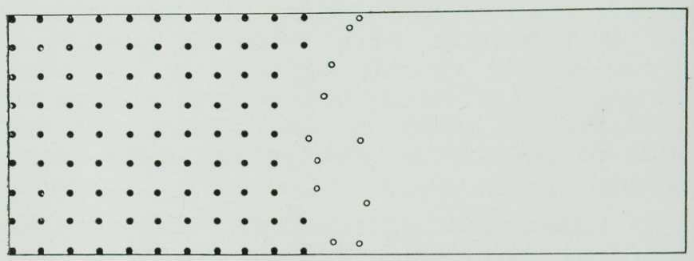

Fig. 24.—*E. rudis*

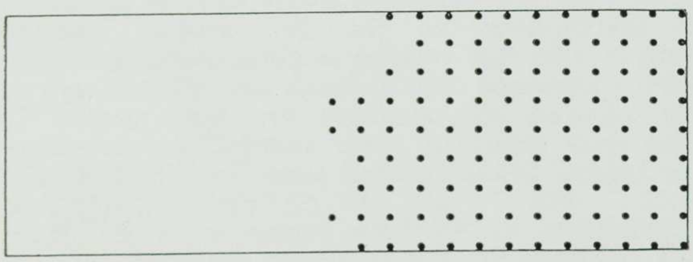

Fig. 25.—*E. salmonophloea*

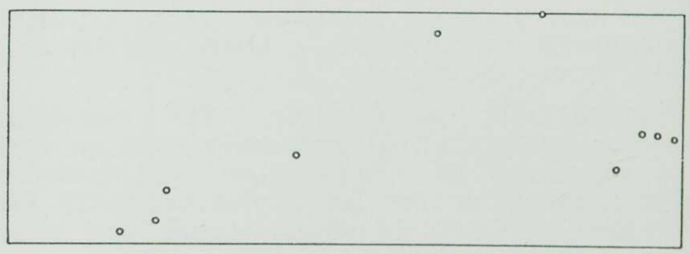

Fig. 26.—*N. floribunda*

Figs. 15-26.—Continuous and disjunct distributions of the 12 tree species defined in the study area. Symbols defined in text.

of the Monkopen deposits. It is notable that while such an effect may simulate conditions of high rainfall in a low rainfall area, there is no situation in the study area to simulate low rainfall in high rainfall regions.

The pedalfer-pedocal transition is the principal soil discontinuity in the area, and this occurs in the region of the 20″ isohyet and the associated transition from internal to external drainage. This line marks the margins of continuous distributions of 4 species in the study area. Within the areas of pedalfers or pedocals, tree species exhibit specificities to surfaces and their associated soils, controlling local patterns of tree incidence. This control of distribution was not revealed by the grid system used to reconstruct the geographic distributions, and was studied by a point sampling procedure.

Surface determinations were made at each of 140 points distributed evenly across a broad median east-west transect of the area. Tree incidence on these surfaces was observed and species were scored as represented or not-represented at each point. Scores from the 140 points were listed as west or east of the 20″ annual rainfall isohyet, to compare species in the areas where their continuous distributions overlap, and scores from the sites of disjunct stands were listed separately. Each of these lists was totalled, and tree incidence-surface interaction was detectable, i.e. certain species never occurred on certain surfaces and certain species always ocurred on certain surfaces. The various species exhibited a range of surface-specificities and conversely, surfaces varied in the numbers of species incident on them. These basic interactions are summarized in Table I, where an entry in the negative (-) signifies that the species so qualified never occurred on the surface referred to, at any of the sample points. Positive entry (+) signifies incidence of the species on the surface referred to, at one or more sample points.

Knowing the associated soils of the different surfaces, the relationships of the different species to the soils in the study area may also be summarized.

Nuytsia floribunda.—Restricted to deep sands derived from laterite and deposited in water-collecting hollows.

Banksia grandis.—Restricted to massive laterite, heavy ferruginous gravel or deep sands derived from laterite and deposited in water-collecting hollows.

Eucalyptus rudis.—Restricted to the situation pertaining in principal watercourses and to wet drainage lines in loams and gritty sands over mottled weathered rock.

Eucalyptus marginata.—Restricted to massive laterite or heavy ferruginous gravel, sometimes adjoining sands deposited in a water-collecting hollow.

TABLE I*

E. marginata	*B. grandis*	*N. floribunda*	*E. calophylla*	
+	—	—	—	Balkuling
—	+	—	—	Belmunging
+	+	—	—	Quailing erosional
+	—	+	—	Quailing depositional
+	+	+	+	Monkopen

E. redunca var. *elata*	*A. acuminata*	*E. loxophleba*	*C. huegeliana*	*E. salmonophloea*	*E. longicornis*	*E. astringens*	
—	—	+	—	+	—	—	Avon
—	—	—	—	—	+	—	Baandee
+	—	—	—	—	—	+	Breakaway face
—	—	+	—	+	—	—	Floodplain sands
—	+	—	+	—	—	—	Granite outcrop
+	—	—	+	—	—	—	Monkopen
+	+	—	—	—	—	—	Quailing erosional
+	+	—	+	—	—	—	Granite sandy soils
—	+	+	—	—	+	—	York
+	+	—	+	—	+	—	Quailing depositional
+	+	—	—	—	+	+	Quailing residual
+	+	+	—	+	—	—	Truncated Mortlock
+	+	+	+	+	—	—	Mortlock
+	+	+	+	+	+	—	Belmunging
+	+	+	+	+	+	—	Sandy alluvium
+	+	+	+	+	+	+	Balkuling

C. huegeliana	*E. redunca* var. *elata*	*A. acuminata*	*E. calophylla*	*E. rudis*	*E. loxophleba*	*E. astringens*	
—	—	—	—	+	—	—	Fresh complex
—	+	—	—	—	—	+	Breakaway face
+	—	+	—	—	—	—	Granite outcrop
—	+	—	+	—	—	—	Monkopen
+	—	+	+	—	—	—	Malebelling depositional
+	—	+	+	—	—	—	Granite sandy soils
+	+	—	+	—	—	—	Kauring
+	+	+	—	—	—	—	Mortlock
+	+	—	+	—	—	—	Quailing depositional
+	+	—	+	—	—	—	Quailing erosional
—	—	+	—	+	+	—	York
+	+	+	+	—	—	—	Belmunging
+	+	+	—	—	+	—	Malebelling erosional
+	+	+	+	+	—	+	Balkuling

* The relationships between surfaces and soils and between surfaces and tree species incidence, described in this paper, do not necessarily apply beyond the study area. For example, on traverses between York and Quairading where essentially similar surfaces occur, *E. salmonophloea* occurs on Balkuling surfaces that are neither calcareous nor derived from basic materials.

Eucalyptus astringens.—Restricted to degraded Quailing, Balkuling and breakaway surfaces. The soils are pink or white weathered rock usually with a scree of ferruginous gravel.

Eucalyptus salmonophloea.—Occurs on valley clays, or sands over domed clays, calcareous or calcareous at depth. It also occurs on those lateritic surfaces which contain secondary lime.

Eucalyptus calophylla.—Occurs principally on non-calcareous sandy soils and on laterite within its continuous distribution. Its relict representation at Toolibin is on relict deep sand deposited in a water-collecting hollow.

Eucalyptus loxophleba.—Occurs on brown gritty sands over mottled weathered rock, on loams, and on calcareous clays and sandy soils. It occurs on those lateritic surfaces which contain secondary lime.

Eucalyptus longicornis.—Occurs principally on calcareous soils associated with valley floors and salt lakes, but occurs also on calcareous laterites and on soils of the Balkuling surface derived from basic parent materials.

Acacia acuminata.—Occurs on various soils, particularly sandy alluvium, loam and granitic skeletal soils. It does not occur on very calcareous clays and sands, or on massive laterite, breakaways, heavy ferringinous gravel or deep sands.

Casuarina huegeliana.—Occurs on various soils, particularly granitic skeletal soils and associated sands but not on very calcareous clays and sandy soils, or on loams or breakaways.

Eucalyptus redunca var. *elata.*—Occurs on many soils, but not on very calcareous sands and clays, or on granitic skeletal soils.

Discussion

The two environmental factors of rainfall and soils have a marked influence on tree distributions in the study area. and the occurrence and distribution of the different soils themselves relates to rainfall, which has brought about soil changes in geological time. In the area studied, margins of continuous tree distributions, the pedalfer-pedocal boundary and the 20″ rainfall isohyet all relate closely. Within areas of continuous tree distributions, incidence patterns relate closely to local soil patterns. Only disjunct tree distributions on soils of some *relict* surfaces do not relate to present rainfall. This is not altogether inconsistent, however, as a high ground-water effect simulates high rainfall conditions in many of these instances, and there is evidence that disjunct distributions relate to past rainfall distribution.

All detected disjunct tree distributions are of species now otherwise distributed west of, or in the west of the study area, in regions of relatively high rainfall. In the case of *E. marginata,* disjunct stands complete a line observed to extend from areas of continuous distribution west of the study area to outliers at Jilakin Rock and Hyden. Similarly, *E. calophylla* and *B. grandis* exhibit eastern disjunct and western continuous distribution. Tree species now distributed continuously east of the 20″ isohyet do not exhibit western outliers.

Disjunct tree distributions are located on old lateritic soils on or derived from Jutson's "old plateau." This was considered to have had broad distribution as a peneplain under conditions wetter than the present and favourable to laterite formation, and to have undergone subsequent arid erosion, resulting in its partial destruction in the interior (Jutson 1955).

Wet climate of the kind necessary for laterite formation has certainly changed in nett effect towards arid conditions, indicated by secondary deposition of lime in relict lateritic surfaces in the east of the study area.

With increase in aridity, the original rainfall and edaphic conditions have retreated westwards, and the sites of disjunct vegetation stands are *relicts* of the original conditions, where high soil-water availability substitutes for rainfall. Aridity permits accumulation of lime, and calcareous soils have extended westwards on the surfaces of the new plateau. Even some relict lateritic surfaces have become calcareous under the drier conditions, and calcareous surfaces have been occupied by species which have migrated westwards as a result.

According to Crocker (1959), who recently summarized the known history of vegetation and climate in Australia, peneplanation and apparent humid climate of the Tertiary limited habitat diversity in Australia, and relatively humid times may have persisted to the early Recent with some arid periods. Subsequent severe aridities in the late Quaternary eliminated many vegetational units and resulted in the retraction of others to more favourable situations. Since that time there has been expansion. The genera studied here, with the exception of records for *Nuytsia*, were apparently all established by the end of the Tertiary.

The simplest hypothesis accounting for the disjunct distributions in the study area is that the species involved had continuous distributions over the area, under the rainfall and soil conditions preceding the most recent aridity.

Acknowledgments

The writer would like to express his thanks to Professor E. J. Underwood and Dr. C. A. Parker, who made this work possible; to Mr. M. Mulcahy for his assistance in the field, and to Mr. D. M. Churchill and Mr. G. M. Storr for the data for Figs. 3-14.

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